

**THE EFFECTS OF BIOCHAR ON THE SOIL PROPERTIES AND ON  
YIELD FORMATION OF PEA (*PISUM SATIVUM* L.) NINE YEARS  
AFTER APPLICATION**

**Samuel Amoah**

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**University of Helsinki**

**Department of Agricultural Sciences**

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## ABSTRACT

Tiedekunta/Osasto Fakultet/Sektion – Faculty Agriculture and Forestry		Laitos/Institution– Department Agricultural Sciences
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<p>Tiivistelmä/Referat – Abstract</p> <p>Biochars, made from biomass heated in limited oxygen, have been suggested as a sustainable means of increasing crop productivity. Two of the most commonly reported benefits of biochars are improved soil water availability and nutrient status, due of which also yield increases have been reported. Most studies so far have focused on subtropical soils that are low in initial carbon content, and cereals have been the main crops studied. There is also lack of knowledge of the effects of biochar in longer term than five years on the yield formation of grain legumes like peas. A long-term field experiment was conducted in Helsinki, Finland to investigate the effects of softwood biochar on the soil properties and on the yield formation of peas. Three levels of biochar rates were used: 0 ton/ha, 5 ton/ha and 10 ton/ha in conjunction with 3 NPK fertilizer levels of 30, 65, and 100 percent of the recommended levels. The addition of biochar was tied to slightly elevated levels of soil moisture at the upper soil layers (0 – 18 cm). This increase was however not significant (<math>p &gt; 0.05</math>). Changes in biochar porosity over the years may have led to decreased water holding capacity of the soil and hence low moisture content. The soil nutrient status was also not significantly affected by biochar additions, except for sulphur levels which recorded a marginal significance of <math>p &lt; 0.1</math>. Changes in biochar properties over time could also be responsible for the lack of effects on soil nutrients. The soil used was relatively fertile (3.5 % C), hence the effects of biochar were insignificant. Fertilizer effects were also not significant, except for significant levels of such nutrient as P, Ca, P and S. The lack of fertilizer effects could be due to the relatively fertile nature of the Luvic Stagnosol soil. The lack of effects of biochar on soil properties resulted in non-significant results for yield components of peas. The relatively dry weather during the growing season could also be responsible for the vast lack of significance recorded.</p>		
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## TABLE OF CONTENTS

<b>ABSTRACT .....</b>	<b>2</b>
<b>Abbreviations and concepts .....</b>	<b>4</b>
<b>1 INTRODUCTION.....</b>	<b>5</b>
<b>2 LITERATURE REVIEW .....</b>	<b>7</b>
2.1 Brief history of the use of biochars .....	7
2.2 Biochar production and characterization .....	7
2.3 Effects of biochars on soil properties .....	9
2.3.1 Effects of biochars on soil water .....	10
2.4 Effects of biochars on yield components .....	11
2.5 Constraints to biochar use.....	12
2.6 Legumes .....	12
2.6.1 Status of cultivation of peas and other legumes in Finland.....	13
2.6.2 Yield formation and yield components of legumes .....	14
<b>3. OBJECTIVES OF THE STUDY.....</b>	<b>17</b>
<b>4. MATERIALS AND METHODS .....</b>	<b>18</b>
4.1 Study area .....	18
4.1.1 Weather conditions .....	19
4.2 Experimental setup .....	20
4.2.1 Soil sampling.....	22
4.2.2 Cultural practices and growth measurements .....	22
4.2.3 Measurements of Chlorophyll content, Leaf Area Indices (LAI) and soil moisture....	23
4.2.4 Sampling and yield components .....	24
4.3 Data Analysis .....	25
<b>5. RESULTS .....</b>	<b>26</b>
5.1 Soil moisture content .....	26
5.2 Soil chemical properties.....	26
5.3 Effects of biochar on yield components.....	29
<b>6. DISCUSSION .....</b>	<b>32</b>
<b>7. CONCLUSION .....</b>	<b>35</b>
<b>8. ACKNOWLEDGEMENTS.....</b>	<b>35</b>
<b>REFERENCES.....</b>	<b>36</b>

## Abbreviations and concepts

**Biochar:** a carbon-rich material made by heating plant remains, animal droppings and/or any other organic substance in oxygen-depleted atmosphere (Green and Wayman, 2013). The heating of the organic waste is slow, done at over 250°C and takes place without the use of oxygen, a process called pyrolysis or charring. This makes biochar very rich in carbon (Chan *et al*, 2008). The International Biochar Initiative (IBI, 2013) explains biochar as: ‘A solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment. Biochar can be used as a product itself or as an ingredient within a blended product, with a range of applications as an agent for soil improvement, improved resource use efficiency, remediation and/or protection against particular environmental pollution and as an avenue for greenhouse gas (GHG) mitigation.’

### List of abbreviations

Ca <sup>2+</sup>	calcium ion
CEC	cationic exchange capacity
GHG	Greenhouse gas
IBI	International Biochar Initiative
K <sup>+</sup>	potassium ion
Mg <sup>2+</sup>	Magnesium ion
N	nitrogen
NH <sub>4</sub> <sup>+</sup>	ammonium ion
P	phosphorus
PCM	pyrogenic carbonaceous materials
WHC	water-holding capacity

## 1 INTRODUCTION

The world's population is projected to reach 9.6 billion people by 2035 (U.N. 2013). World food security is threatened by loss of soil fertility and reduced crop yields through acidification of soils, surface compaction, nutrient loss, etc. (Smith et al. 2015a; Smith and Gregory, 2013). Overcultivation and unsustainable agricultural practices ultimately lead to loss of soil fertility (De Meyer et al. 2011). There is therefore the need for more effective and sustainable means of enhancing soils to increase productivity. Biochar is one such sustainable means that has received attention over the past few years due to it being environmentally friendly. Biochar has been reported to improve soil fertility by increasing soil carbon, enhance water holding capacity and other soil physicochemical features as well as supporting soil biota (Lehmann et al, 2015).

Biochar, made from pyrolysis of organic substance like wood and manure (Lehmann et al, 2015), has been around for millennia, but it is until recently that research has intensified. The surged interest is due to its reported role in helping to mitigate climate change due to high stability of aromatic compounds in it and a shift towards more sustainable soil management practices (Chan *et. al*, 2008). Biochars have been reported to help in sequestering carbon, improving soil water dynamics and overall increasing productivity by altering soil fertility (Lehmann & Joseph, 2015; Kuppusamy et al, 2016). Biochars affect the soil in many ways: by altering soil Ph, water holding capacity, bulk density, nutrient availability and release of organic carbon (Lehmann et al, 2015a). One of the most commonly reported benefits of biochar on crop production is increased yield (Jeffery et. al, 2011). Biochar has been reported to both increase and decrease crop yields (Liu et al. 2013; Jeffery et al. 2015a). The yield responses are due to several factors including changes in pH and solute composition (Van Zwieten et al., 2010; Rajkovich et al., 2012)

Despite the numerous reported benefits of biochar, there has been little work on the effects of biochar on yield formation of legumes, especially peas. The bulk of biochar findings have come from studies with cereals in warmer climates. In addition, most of the work focusing on the effects of biochar on crop production have focused mainly on the short-term effects. There are currently not enough studies focusing on how aging biochar affects soil properties and ultimately plant yield. This study sought to investigate the long-term effects of an eight-year-old biochar on a temperate Finnish soil including its effect on soil pH, moisture content,

nutrient composition and eventual yield of peas. First time biochar application was done in 2010. This study was part of a larger research of the Agrichar Research Group of the University of Helsinki.

## 2 LITERATURE REVIEW

### 2.1 Brief history of the use of biochars

Smith in 1879 and Hartt in 1885 (Woods, 2003), described the existence of biochars as very fertile soils called *Terra Preta do Indo* in Portuguese (black earth) by the Indians of the Amazonia although they could not prove their origins. Studies of these soils have revealed they have high organic matter, high moisture content, high water exchange ability, high cationic exchange capacity and increased microbial activity (Lehmann & Joseph, 2009). It has been suggested that these fertile soils were attained by gradual deposition of burning vegetations and other biomass as well from remains of dead animals (Falcao, 2012). The dark colour of the Terra Preta has been attributed to the ancient farming practices of the Amazonian Indians such as slash and char (Talberg, 2009). There has also been evidence to suggest that biochar applications may have been deliberate considering the quantities present in those areas (Sohi, Krull et al. 2010) as one way to address the low soil fertility. For example, the abnormally high nutrient content of the *Terra Preta* has been attributed to deliberate processes such as slash and char, nutrient enrichment through composting and use of human excreta.

There have also been records of similar soil types in other parts of the earth including Benin in West Africa and in the savannas of South Africa (Lehmann et al., 2007). Recent discoveries of such soil types have been made in Mexico and Borneo (Sheil et al., 2012), in the United States (Skjemstad et al., 2002; Laird et al., 2009) and in Japan (Ishii & Kadoya, 1994). These findings suggest that improving soil fertility by adding plant biomass was a commonplace around the world. In Finland and surrounding areas, there was a comparable practice called *kytö*. This was a kind of biochar produced by burning of wood or peat, was used in Finland and nearby areas as a means of improving soil fertility and reducing the incidence of pests and diseases (Ahokas 2012). The Dutch scientist Wim Sombroek in his publication 'Soils of the Amazon' noted these various soils and promoted the idea of developing new black earths as storages for carbon for intensive crop production (Woods & McCann, 1999; Neves et al., 2003).

### 2.2 Biochar production and characterization

Although sometimes classified as a form of charcoal, biochars have certain properties that differentiate them from regular charcoal. The use of biochar as soil improvement substance or in any other way that does not allow rapid mineralization of the biomass carbon back to

atmosphere (EBC 2012) distinguishes it from the usual charcoal which is used widely for energy production (Lehmann & Joseph, 2009). Both charcoals and biochars are described as pyrogenic carbonaceous materials (PCM), implying that they are produced by pyrolysis; the thermochemical breakdown of organic substrates in the presence of limited or no oxygen. The heating of the biomass can be fast or slow. Slow pyrolysis occurs at very high temperatures (400 – 550° C) for a few seconds whereas fast pyrolysis typically occurs at temperatures less than 400 o C for relatively longer periods, over 30 minutes (Lehmann, Joseph 2015).

Several raw materials can be used in producing biochars, the commonest cited materials being crop residues, dry plants, tree biomass, waste paper, organic waste from urban settlements, etc. (Escalante, Pérez et al. 2016). The composition of the organic materials used in the production ultimately affects the nature of the biochar. Similarly, the way in which the biochar was produced has effects on the physicochemical properties of the biochar product. Biochar's effect on the soil properties eventually would depend on the production parameters and the feeding stock used in the production (Lehmann, Joseph 2015, Schmidt, Noack 2000). For example, contamination of the feedstock will result in a more heterogeneous biochar. Biochar feedstocks includes organic materials such as farm residues, droppings from animals, municipal wastes, etc. The processing parameters may include size of reactors, rate of heating, pressure applied, heating time and also post-heating processes such as drying or activation (Lehmann, Joseph 2015). Thus, many different effects of biochar on the applied soil are possible due to the processing parameters and the feedstock used.

Biochar can be made in the same way as the production of traditional charcoal, in kilns. However, this form of production cannot be properly controlled and contributes to air pollution and is therefore unsustainable (Lehmann, Joseph 2015). It is therefore important that more effective and environmentally sustainable methods are used in the production of PCMs which yield more char and subsequently less pollution. Currently, there are many sophisticated systems for producing PCMs including the drum and rotary kilns. Using these advanced methods makes control of the process precise and the physicochemical properties of the resultant biochar can be controlled through the feedstock selection systems (Spokas, Cantrell et al. 2012) .



### 2.3 Effects of biochars on soil properties

Biochar has different physical and chemical properties compared to normal soil. For example, the physical differences between biochar and soil changes the tensile strength and water retention ability and other important features of the soil (Lehmann *et al.*, 2011). The specific effects depend on the nature of biochar used and the substrate soil. Biochar has great potential for use as soil amendment. Biochar has the capacity to improve greatly the fertility of the soil in addition to sequestering carbon from the atmosphere and storing for long periods (Van Zwieten, Kimber *et al.* 2010a, Lehmann, Gaunt *et al.* 2006, Sohi, Krull *et al.* 2010). Incorporating biochars into soils may change such physical properties of the soil as texture, structure, pore size distribution, total surface area and bulk density (Lehmann *et al.*, 2015). These changes in turn affects the soil's aeration and water holding capacity, tillage and plant growth. Generally, biochar improves soil cationic exchange capacity (CEC) by retaining important ions such as  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  because of biochars' negative surface charges (Escalante *et al.*, 2016). The specific effects depend on the nature of biochar used and the substrate it is applied to. Addition of biochars to soils help increase their nutrients retention ability (Lehmann *et al.*, 2015), thereby reducing the need for added fertilizers (Glazer *et al.*, 2001). Ding *et al.* (2016) suggested four main ways in which biochar helps in improving soil (figure 1)

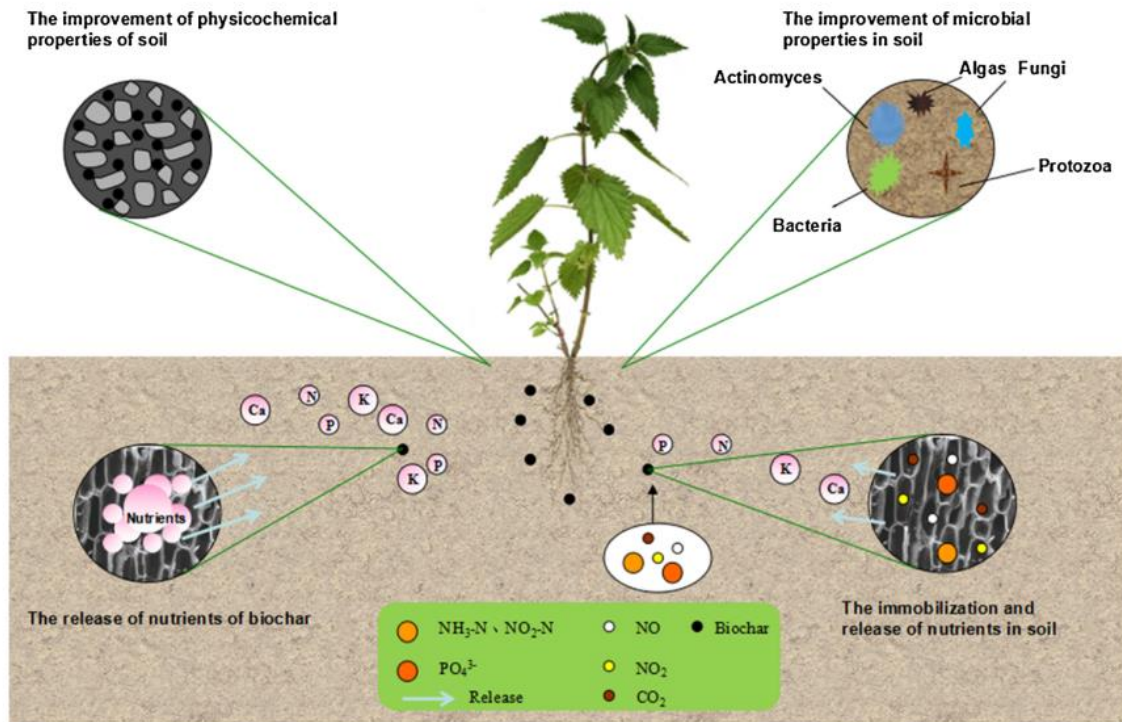


Fig.1: Four main ways biochar affects soil fertility (Ding *et al.*, 2016)

Biochar has been shown to contain substantial amounts of important nutrients and can be used to amend poor soils. For example, fresh biochar has been reported to contain and potentially release large amounts of N and P (Bian et al., 2013). The ash portion of biochars is rich in important elements including K, Na, Ca and Mg (Rajkovich et al. 2012). Following biochar addition, the levels of extractable K, Ca, Na and Mg in the soil rose by a range of 60 – 670 % (Wang et al. 2014). Similarly, total soil C increased from 2.27 to 2.78 %, total N rose from 0.24 to 0.25 % and a P increased from 15.7 to 15.8 mg kg<sup>-1</sup> (Jones et al. 2012). It was reported that amending the ferrosol soils with biochar increased biomass production in soya bean and radish due to increased N uptake in wheat (Van Zwieten, Kimber et al. 2010b). Biochars have been shown also to increase soil pH (Van Zwieten, Kimber et al. 2010a). For example, rice husk biochar increased soil pH from 3.33 to 3.63 (Wang et al. 2014). Increases in pH lead to better adsorption of nutrients to the roots of plants ((Ding, Liu et al. 2016). Cationic exchange ability (CEC), an indirect measure of how effective soils retain water or nutrients, has been shown to increase following the addition of biochars (Laird, Fleming et al. 2010).

### **2.3.1 Effects of biochars on soil water**

Improved soil water holding capacity is one of the most reported effects of biochar. It is still unclear the underlying mechanisms by which biochar affects soil water levels (Sohi et al. 2009a). Hardie et al. (2014) proposed that added biochars might improve and stabilize soil pore structure leading to increased porosity and hence higher water holding capacity. Similar studies have suggested that the porous nature of biochars leads to creation of new pores by addition of biochars to the soil, and therefore improve soil physical parameters (Sohi et al. 2010; Atkinson et al. 2010; Major et al. 2009). Due its high porosity and numerous tiny pores, biochar holds water for plant use and helps in proper soil drainage (Asai et al. 2009). Biochar was reported to alter soil water holding capacity by decreasing soil bulk density (Abel et al. 2013) According to Peake et al. (2014) biochar could enhance water-holding capacity by over 22 %.. Biochars can help to loosen up compact soils thereby improving aeration and water holding capacity. According to Peake et al. (2014), biochars can help to decompactify soils by as much as 10 %. Mixed results of investigations into the effects of biochar on soil water levels have been reported. Biochar had no significant effect on soil moisture content after 2.5 years of its incorporation into Planosol soils in Tasmania (Hardie at al., 2014). According to Gascó et al (2018), the application of biochars derived from animal waste led increased soil water available

for plant use. Wang et al. (2019) suggests that biochars effect on soil water depends on pore size and soil texture. They reported that biochars with high pore volume led to increased plant available water until pore size changed. Biochar addition led to increased soil water content by decreasing soil bulk density (Abel et al, 2013). The increased water holding capacity of the soil following biochar treatment may be partially responsible for the improved yields (Jeffery et al., 2011)

## **2.4 Effects of biochars on yield components**

Much has been researched about effects of biochar on yield, biomass production, soil structure and properties, soil biota, etc. Gavili et al (2019) reported that moderate biochar treatments (1.25 wt. %) of cow manure biochar to arid Regosols in Iran led to significantly increases in biomass of soybean (both fresh and dry straw weight), pod sizes and overall plant height. The cattle-manure biochar also increased leaf area index in all application rates. In a controlled pot experiment using oil palm empty fruit bunch biochar (EFBB), Bakar et al (2015) reported overall yield increase of rice by up to 472 %. They also reported that 40 t / ha biochar applied increased the number of tillers from 28 to 80 compared to the control pots.

Treatment of German luvisol soil with peanut husk biochar significantly increased in biomass yield of rye grass (*Lolium perenne* L.) compared to controls (Kammann et al., 2012). Jin et al (2019) suggested that amendment of red soils (Ultisols by the USDA) may temporary increase rapeseed yield and yield component relative to the control. A three-year field trial by Jones et al., (2012) reported an increase in above ground biomass of maize. Similarly, an increase in both the above ground and below ground biomass yield of rice was reported when highly weathered ferrosol soils were treated with charcoal (Glaser et al., 2002).

The effects of biochar on the yield of a crop will depend on several factors. Among these factors are the rate of application, the type of crop, the kind of soil used in cultivation, the nature of the biochar used in the study, the experimental design, etc. (Lehmann & Joseph, 2015). Nevertheless, addition of biochar to soils does not always lead to increased yield or biomass. For example, Lentz and Ippolito (2012) recorded no significant increase in yield of corn despite the addition of 24.4 Mg / ha of hardwood biochar during a two-year period. Even though, moderate biochar amendment (5 – 30 t/ha) of saline soil led to about 2.9 – 19.4 % increase in wheat grain yield, application rates over 30 t/ha biochar negatively affect overall grain yield (Sun et al. 2019)

Similarly, Schnell et al. (2012) found no increase in sorghum yield and biomass after application of 3 Mg / ha of sorghum biochar to an alfisol soil. In another experiment on soil treated with 10 Mg / ha of sugar beet pulp biochar, the development of the sugar beet after germination slowed rapidly and led to a reduced yield relative to the control experiment (Gajić & Koch, 2012). Thus, biochar application can both increase or decrease crop yield. Thus, biochar application can both increase or decrease crop yield. There is the need for more research into the various mechanisms of biochars interaction with soil and its effects on plant productivity.

## **2.5 Constraints to biochar use**

Biochar use has been gaining unprecedented attention in the last few years and it is necessary to discuss potential negative effects that biochars may present. There is still a lot of unknowns about how biochars work and it is prudent that more research is undertaken to understand the different conditions presented by various types of biochar (Fang et al., 2012). There have also been concerns raised about the possibility of biochar changing the composition of microorganisms in the soil (Kim et al, 2007, Pietikäinen et al, 2000). Being used as a soil improvement, biochar can help promote the growth of certain weed species in the field. There is however not much research done on the effects of biochar on weed growth in fields and how much it affects overall crop yield. Mitchel (2015) reported that biochar increased the weed growth and dry biomass in common weeds such as barnyard grass and redroot pigweed respectively. Major et al. (2005) also reported that biochar use alone did not necessarily increase weed growth but when used together with inorganic fertilizers, weed cover increased significantly. Another potential drawback to the wide usage of biochar is the high cost of biochar production.

## **2.6 Legumes**

Legumes are an important source of food for almost every community. Aside cereals, legumes are the most important food source and the most cultivated agricultural crop (Graham & Vance, 2003). Legumes belong to the family Leguminosae (Fabaceae) and are among the largest group of flowering plants. There are about 18,000 – 19,000 legume species in about 670 – 750 genera (Polhill 1981). There are many varying uses of agricultural legumes. Aside being an important protein source for humans and livestock, many legumes are used in making vegetable

oils. For example, soybean and peanuts are used in making about 35% of all vegetable oils (Graham & Vance, 2003). An important characteristic of legumes is their ability to fix atmospheric nitrogen. Wood leguminous plants such as *Acacia*, *Erythrina*, *Calliandra*, and *Parkia* are now included in agroforestry systems to improve soil fertility by fixing nitrogen (Sprent & parsons, 2000). Legumes have many other uses apart from the traditional usage. For example, some legumes have been successfully being used to make biodegradable plastic materials (Paetau et al., 1994). Some legumes have been proven to have medicinal properties. Compounds such as isoflavones derived from soya bean have been shown to reduce blood cholesterol and decrease susceptibility to cancer (Kennedy, 1995; Molteni *et al.*, 1995).

Peas are one of the most important legumes. Field peas are classified in the sub-family Papilionaceae (Cousin 1997) and have been cultivated for over 7000 years (Smartt 1990). The plant is thought to have originated from South Western Asia and later spread to the Mediterranean (Cousin 1997) and other parts of the earth. The pea plant typically has well-developed taproot system, growing over 100 cm downward. Pea growth is indeterminate with wiry stems. Leaf colour usually assumes various forms of green from dark green to yellowish green (Ayaz 2001, Cousin 1997). Leaf and stem surfaces are waxy. The plant has pinnate alternate leaves with tendril endings. Peas bear white to purple self – pollinated flowers (Cousin 1997). Matured fruits are dry pods bearing about 3 – 11 seeds (Somaatmadja 1989)

### **2.6.1 Status of cultivation of peas and other legumes in Finland**

The cultivation of grain and forage legumes account for about 12 – 15% of all arable land cultivation on the earth (Graham & Vance, 2003). Grain legumes, mainly peas and faba bean were cultivated on an estimated area of 29,392.86 ha (Mavi, 2018) Finland is situated in the boreal region characterized by long cold winters and a short growing season. This limits the number of plant species that can be grown in those relatively harsh conditions. The main crops grown in boreal regions including Finland include rapeseeds, sugar beets, potatoes and a few cereals. The cultivation of grain legumes has not received much attention compared to the other crops (Stoddard *et al.*, 2009). Low cultivation of grain legumes has resulted in increased imports of soya bean and other legumes.

Peas (*Pisum sativum*) are among the major grain legumes cultivated in Finland on about 3000 ha of land (FAO 2013). According to LUKE (2018), Finland recorded over 120 % increase in cultivation area of peas from 2017 to 2018. Peas were cultivated on some 8600 ha of land in

2018 compared to about 4200 ha in the year 2017. The average yield of peas from the year 2008 – 2017 was 2,380 kg/ha. The overall pea yield increased from Alongside faba beans, peas have a long history of cultivation in Finland dating back to about 500 BC (Stoddard *et al.*, 2009). There is enough evidence of pea cultivation in Finland since the 1600s and 1700s. Peas were grown mostly in the South-Western fertile belt (Grotenfelt, 1922). Over the years, there have been extensive research into breeding and development of pea varieties better suited to growing under Finnish conditions and to consumer requirements. Peas and other legumes were bred for such traits as lodging resistant, yield and early maturity (Stoddard *et al.*, 2009)

### 2.6.2 Yield formation and yield components of legumes

Several factors contribute to the yield of a crop. It is important to note that the yield of grain legumes varies greatly (Hay 1995). Understanding the numerous biological processes affecting growth and development as well as the effects of the environment on yield provides a good measure of yield potential (Dapaah *et al.*, 2000). Effective utilization of water, nitrogen, solar radiation and other available resources determine the final yield by driving photosynthesis and hence partitioning of assimilates. According to Hay & Porter (2006), the partitioning of photosynthates in legumes involves an interplay of numerous physiological, environmental and management processes. Hay and Porter (2006), summarized the distribution of dry matter in soybean with time (figure 2). From germination, most of the resources is channelled into formation of new leaves until the plant begins bearing flowers, from whence a greater majority of dry matter is spent on supporting the reproductive parts. Upon grain filling, most dry matter is then partitioned to pods and grains

The components of yield method of quantifying plant yield considers all the necessarily parts of the plant in terms of their numbers, weight and/or sizes. This concept of yield components has been employed in accounting for the differences in yield in many grain legumes including *Phaseolus vulgaris* (Dapaah 1997), chickpeas (Verghis 1996) and peas (Moot 1993). For example, the total seed yield (TSY) of grain legumes is calculated using the formula:

$$TSY = \left( \frac{\text{plants}}{m^2} \right) \times \left( \frac{\text{pods}}{\text{plant}} \right) \times \left( \frac{\text{seeds}}{\text{pod}} \right) \times \text{mean seed weight} \quad (\text{Ayaz 2001})$$

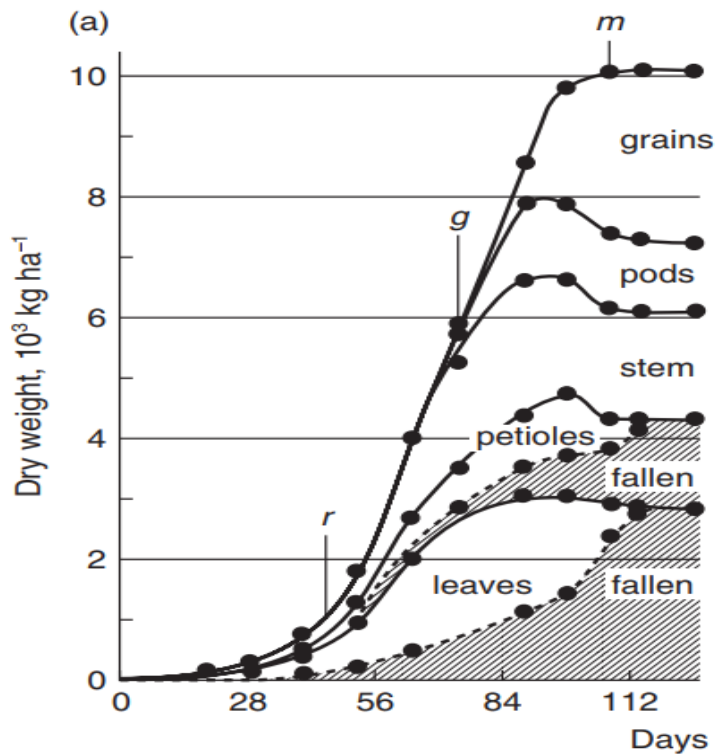


Figure 2. The distribution of dry matter in Soya bean over time. Here *r* is start of reproductive phase, *g* is initiation of grain formation and *m*, is where crop is matured (Adapted from Shibles et al. 1975)

Legume seed yield can be quantified in terms of the number of pods per plant, seeds per pod or seed weight (Ayaz 2001). For example, Ohyama et al. (2013) summarized the yield components of soybean in figure 3 below.

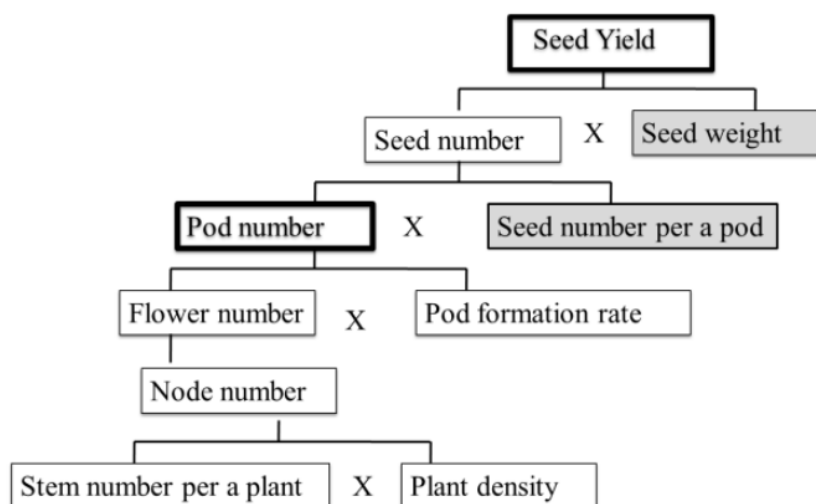


Figure 3. diagrammatic representation of soybean yield components. Taken from (Ohyama, Minagawa et al. 2013).

The first established yield component is plant density (number of plants / m<sup>2</sup>). Controlled mainly by the farmer, the plant density ultimately affects legume growth and all other latter yield components including the number of pods. High plant density leads to reduced stem branching due to increased competition for sunlight and nutrients (Ohyama et.al, 2013; Hay & Porter, 2006; Lopez – Bellido, 2005). In the vegetative stage of development, there is an inverse relationship between plant density and total number of stems per plant. At low planting density under favourable conditions<sup>3</sup>, there is increased side branching (Lopez-Bellido, 2005).

According to Ohyama et al (2013), the most important yield component in legumes is the number of pods / m<sup>2</sup> (Figure 3). The average number of seeds / pods is mostly constant. The prevailing conditions of growth in latter development stages determines the average weight of the seed. Legumes adapt their growth to prevailing environmental condition (sunlight, soil conditions, and water availability). The total seed yield can be drastically reduced by for example invasion by pests such as rodents, birds, etc. (Ohyama et al, 2013) It is generally expected that maximum yield is observed when each of the components of yield is highest. There are however a few demerits to this method of quantifying yield. These components of yield are greatly influenced by species' genotype, environment and management practices used in production (Gardner et. al, 1985). There exists an interdependency relationship among yield components. This relationship is called 'plasticity' ensures that an increase in one component does not necessarily lead to a commensurate increase in total yield (Moot 1993).

Legume yields depend on many biotic and abiotic processes. Environmental processes such as precipitation, photoperiod, sunlight, etc and other biotic stresses including pests and pathogens can greatly reduce legume yield (Ohyama et al, 2013). The ability of legumes to compensate for changes in resources depends on the length of the vegetative period and the prevailing weather conditions. Drought seriously affects total legume yields. Drought during the vegetative stage of legumes has been reported to be significantly responsible for low yields recorded (Daryanto et. al., 2015). Drought stress may reduce legumes yield by decreasing the length of the reproductive phase and decreasing pod number per m<sup>2</sup> through decreased branching (Fredericks et. al., 1991; Fredericks et. al., 2001). Yield is also reduced in legumes through reduced number of seeds/pod and reduced single seed weight (Dogan et. al, 2007). According to Daryanto et. al, (2015), drought in early part of the reproductive stage (flowering) has more pronounced effects on yield compared to drought in latter stages.



### 3. OBJECTIVES OF THE STUDY

The main aim of the study was to determine the long-term effects of different biochar application rates (0 ton / ha, 5 ton / ha, and 10 ton / ha) and NKP fertilizer (30%, 65 % and 100% of recommended level) as well as their interactions on the soil properties and yield of pea (*Pisum Sativum* L) nine years after it was applied. The specific objectives of the study were to determine the long-term effects of biochar, fertilizer application rate and their interactions on:

- i. soil moisture content
- ii. other chemical properties of the soil; soil carbon to nitrogen ratio (C: N), pH, electrical conductivity and available nutrients including calcium, potassium, phosphorus, magnesium, sulphur, copper, zinc and manganese
- iii. yield components and yield formation of peas.

These objectives were based on the hypotheses that biochar addition to soils enhances the physical and chemical properties of the soil such as nutrient retention, ionic exchange ability and soil moisture. Physical properties such as bulk density of the soil are also expected to decrease (Tammeorg, Simojoki et al. 2014a, Tammeorg, Simojoki et al. 2014b).

## 4. MATERIALS AND METHODS

### 4.1 Study area

The experiment was conducted in the 2018 growing season at the Porvoontienvarsi field, Viikki (figure 4). experimental Farm of the University of Helsinki, Finland ( $60^{\circ}13'27.2''\text{N}$   $25^{\circ}01'38.1''\text{E}$ ) (fig. 4). The field's soil type is described as fertile Luvic Stagnosol (WBR, 2007). Biochar research at the experimental site commenced in the year 2010, when the one-time biochar application was done. Prior to the beginning of biochar research on the field, spring wheat and rapeseed were cultivated on the field for four seasons. Various crops have been cultivated on the field since the biochar application including barley, wheat, rapeseed, faba bean, some grasses etc. The table 1 below illustrates the history of biochar research on the field since 2010.



Figure 4: Aerial view of the Porvoontienvarsi field

**Table 1.** History of cultivation on the subfield since commencement of biochar studies

<b>Year</b>	<b>Crops grown</b>	<b>Fertilizer used</b>	<b>Fertilizer Application rates (recommended %)</b>
<b>2010</b>	turnip rape	Agro 28-3-5	100, 65, 30
<b>2011</b>	wheat	Agro 28-3-5	100, 65, 30
<b>2012</b>	Faba bean	Agro 16-7-13	100, 65, 30
<b>2013</b>	cover grass	Agro 16-7-13	100, 65, 30
<b>2014</b>	Red clover	PK 3-5-20	100, 75, 50
<b>2015</b>	Timothy grass	PK 3-5-20	100, 65, 30
<b>2016</b>	barley	All crop needs covered	100, 65, 30
<b>2017</b>	oats	All crop needs covered	100, 65, 30

#### **4.1.1 Weather conditions**

The planting season started in May 2018. The weather conditions during the growing season varied greatly. In the year 2018, the weather was relatively dry. Rainfall figures were relatively lower compared to the past two growing seasons (see table 3). For example, the highest monthly precipitation during the growing season was 62.3 mm. This is low compared to the highest monthly rainfall value for the preceding growing season (86.1 mm). The summer of 2018 was warm. The mean monthly temperatures recorded were each at least 2 degrees warmer than the previous two growing seasons. Table 2— below summarizes the weather conditions during the growing season compared to past two growing seasons.

**Table 2.** Mean monthly air temperature (° C) and precipitation (mm) values recorded during the growing season and the two previous growing seasons. Data obtained from Finnish Meteorological Institute, 2018.

Year	Mean monthly temperature (° C)				Monthly precipitation (mm)			
	May	June	July	August	May	June	July	August
2016	14.2	15.4	17.8	16.2	7.3	143.8	59.3	59.1
2017	9.8	13.7	16.0	16.2	16.1	13.7	31.2	86.1
2018	15.5	15.8	21.3	18.6	7.8	36.8	36.9	62.3

## 4.2 Experimental setup

The biochar used was made from Norway spruce (*Picea abies* L.) and pine, obtained from Presco Oy in Lempäälä, Finland. The experimental plots were treated with biochar made from spruce (*Picea abies* L.) and / or pine (*Pinus Sylvestris* L.) by charring the wood chips at around 550 – 600 ° C for about 10 – 15 minutes. The biochar produced was applied in 2010 by spreading unto the soil with a sand spreader and later made to be mixed into the top 10 cm layer of the soil using two a rotary power harrow (Tammeorg, Simojoki et al. 2014a). The experiment was set up using a split-plot experimental design having four replicates to determine the effects of the biochar on the soil properties as well as on the yield of pea. Simultaneously, on the adjoining side of the same field, barley and oats were experimented on using the same split-plot design with four replicates. Each plot measured 2.2 × 10 m. A 10 m corridor was allowed between replicates with a 3 m corridor separating one crop from the other (figure 5). The pea variety used was Astronaute.

← Tilanhoitajakaari				Patterinpellonraitti				N
Nro	I	Nro	II	Nro	III	Nro	IV	
<b>Barley</b>								<b>Treatments</b> BC rate A 0 t/ha B 5 t/ha C 10 t/ha Fert rate 1 30% 2 65% 3 100%
117		130		143		156		
116	B3	<b>129</b>	<b>C1</b>	142	A2	<b>155</b>	<b>C3</b>	
115	B2	128	C2	<b>141</b>	<b>A1</b>	154	C2	
114	B1	<b>127</b>	<b>C3</b>	<b>140</b>	<b>A3</b>	<b>153</b>	<b>C1</b>	
113		126		139		152		
<b>112</b>	<b>A3</b>	125	B2	138	C2	<b>151</b>	<b>A3</b>	
111	A2	124	B1	<b>137</b>	<b>C3</b>	<b>150</b>	<b>A1</b>	
<b>110</b>	<b>A1</b>	123	B3	<b>136</b>	<b>C1</b>	149	A2	
109		122		135		148		
<b>108</b>	<b>C3</b>	<b>121</b>	<b>A1</b>	134	B1	147	B1	<b>Bold=TDR</b>
107	C2	<b>120</b>	<b>A3</b>	133	B3	146	B3	
<b>106</b>	<b>C1</b>	119	A2	132	B2	145	B2	
105		118		131		144		
<b>Peas</b>								Corridor 3 m
65		78		91		104		
64	B3	77	C1	90	A2	103	C3	
63	B2	76	C2	89	A1	102	C2	
62	B1	75	C3	88	A3	101	C1	
61		74		87		100		
60	A3	73	B2	86	C2	99	A3	
59	A2	72	B1	85	C3	98	A1	
58	A1	71	B3	84	C1	97	A2	
57		70		83		96		
56	C3	69	A1	82	B1	95	B1	
55	C2	68	A3	81	B3	94	B3	
54	C1	67	A2	80	B2	93	B2	
53		66		79		92		
<b>Oats</b>								Corridor 3 m
13		26		39		52		
12	B3	25	C1	38	A2	51	C3	
11	B2	24	C2	37	A1	50	C2	
10	B1	23	C3	36	A3	49	C1	
9		22		35		48		
8	A3	21	B2	34	C2	47	A3	
7	A2	20	B1	33	C3	46	A1	
6	A1	19	B3	32	C1	45	A2	
5		18		31		44		
4	C3	17	A1	30	B1	43	B1	
3	C2	16	A3	29	B3	42	B3	
2	C1	15	A2	28	B2	41	B2	
1		14		27		40		
Corridor 3 m				10 m				Viikinitie
← Tilanhoitajakaari								↓

**Figure 5:** Field map of the Porvoontie (PT) field of the Agrichar research group for the year 2018. The photo shows the various crops sown, the replicates, corridors as well as the biochar and NPK fertilizer treatment rates for the various plots.

The main plot factor was the biochar application rates with the subplot factor being the rate of application of NPK fertilizer. The biochar levels used on the plots were 0 DM/ha (A), 5 t DM/ha (B) or 10 t DM/ha (C). The N-P-K fertilizer was applied at 30% (1), 65% (2) and 100% (3) of the level of recommended nitrogen for the crop (figure 1). Before application of fertilizer, the field was ridged to miss up the soil. The peas were sown after ridging at a depth of 7 cm with the fertilizer application depth at 9 cm. The individual plots were raked after sowing to cover up any exposed seeds.

#### **4.2.1 Soil sampling**

Soil samples were taken from each plot before fertilizer application and sowing and after harvesting. Using a soil sampler, a sample of soil was taken up to the 15 cm mark. For each plot, 16 of such samples were taken: three from each of the 4 corners of the plot and 4 from the middle of the plot, after which they were thoroughly mixed. The carbon (C), nitrogen (N) and micronutrient content of the soil as well as the organic matter content, pH and electrical conductivity were determined before planting and after harvesting

#### **4.2.2 Cultural practices and growth measurements**

The plants were sprayed against aphids using Basagran M75 on 7.6.2018 and 9.6.2018. A huge flock of wild geese invaded the premises of the field towards the end of June. They fed most on the young leaves of the peas leaving just stems (figure 6). Poles were placed at vantage points on the fields to scare the birds off. Plant recovered from this after a few weeks by growing new leaves after a few days. In addition, a large of pigeons frequented the peas and begun feeding on them. This made it difficult to take 3 x 50 cm samples at the end of the season. On some plots, sampling had to be done all over the field, and not from the ends, to get the required quantity. No external irrigation was provided during the growing season. The development stage of the peas was determined every week until harvesting. Development stages were estimated using the BBCH-scale for legumes. Pea density was estimated during the first sampling by counting the number of peas stems along a 50 cm long stick. The 50 cm stick was placed 3 times randomly such it was at least 1 metre from each rear end and from at least the 3<sup>rd</sup> row of peas from each side.





Figure 6. Photo of the peas after the field was invaded by wild geese

#### **4.2.3 Measurements of Chlorophyll content, Leaf Area Indices (LAI) and soil moisture**

During the 2018 growing season, both the chlorophyll content and leaf area index (LAI) were measured periodically. The Chlorophyll content was measured using a SPAD–502 chlorophyll meter. For each plot, 20 SPAD measurements were taken and averaged as the value for the whole plot. The leaf area index (LAI) simply measures the area of leaves per unit ground area (Chen, Black 1992) and tells about the general state of vegetation. Measurements of LAI were undertaken once during the growing season. LAI was measured using SunScan probe v1.02R (C).

During the growing period, the soil moisture content of the field was regularly monitored. Apart from natural precipitation, no external means of irrigation was provided to the field. Soil moisture levels were measured weekly using a Time Domain reflectometer (TDR). Moisture content was measured at various depths of the soil which included 15 cm, 28 cm and 58 cm deep. The TDR sticks were installed on plots with extremes of biochar-fertilizer application rates i.e. plots with no/maximum biochar and those with least/most fertilizer (see figure 1). Soil moisture content was also monitored for a few weeks after harvesting.

#### 4.2.4 Sampling and yield components

At the end of the growing season when all pods had matured and were fully dried (development stage > 89), sampling for above ground biomass (AGB) was conducted. The samples were taken only from one end of each plot within  $2 \times 2$  m area. A 50 cm stick was placed in a random row within the designated area of the plot. All pea plants along the 50 cm row were carefully plucked from the soil along with their roots if possible. This process was done three times on each plot. The samples were then bagged in a 3 kg paper bag and placed into ovens to dry for 72 hours at 60° C. Table 3 below simplifies the various measurements and samplings taken during the experimental period and the times they were conducted. After samples had been dried, an analysis of yield component was performed for each sample. To do this, the above ground biomass (by weight) of each sample was determined by separating pods, leaves / tendrils and stems. The weight of leaves, stems and pods were determined. The number of plants per sample, the number of pods per sample, number of pods per plant were also determined. The pods were then threshed to separate the seeds and the number of seeds for each sample was determined. Total weight of seeds from each sample was also determined. Figure 7 below illustrates some of the yield components.



Figure 7: Photograph of separated parts of one sample. Each sample was separated into various parts and their weights and / or numbers determined.



Table 3: Measurements carried out on the field during the growing season

Measurement	Dates measured / performed	Materials / methods used
Field preparation	17.05.2018	Rotary power harrow to 12 cm depth
Sowing of peas	18.05.2018	2-m wide sowing machine
Development stage	Once / week 31.05 – 15.08.18	Eye observation by comparing to BBCH-scale (Meier 2001)
Leaf area index (LAI)	26.06.2018	SunScan probe v1.02R (C) JGW 2004/01/19
Plant density	13.06.2018	Counting number of plants within a random row along a 30 cm stick.
Chlorophyll content	10.7.2018	SPAD 502DL Plus Chlorophyll Meter (Konica Minolta Sensing Inc, 2003)
Plant sampling	26.06.2018 10.07.2018 10.08.2018	Stick measuring 30 cm placed within each plot 3×
Soil moisture	Once / week 31.05 – 19.09.18	Time-domain reflectometer (TDR) machine (MiniTrase 6050X3, Soil moisture Equipment, Santa Barbara, USA)
Harvest	13.08.2018	Combine harvester.
Post-harvest soil sampling	10.09.2018	Soil sampler

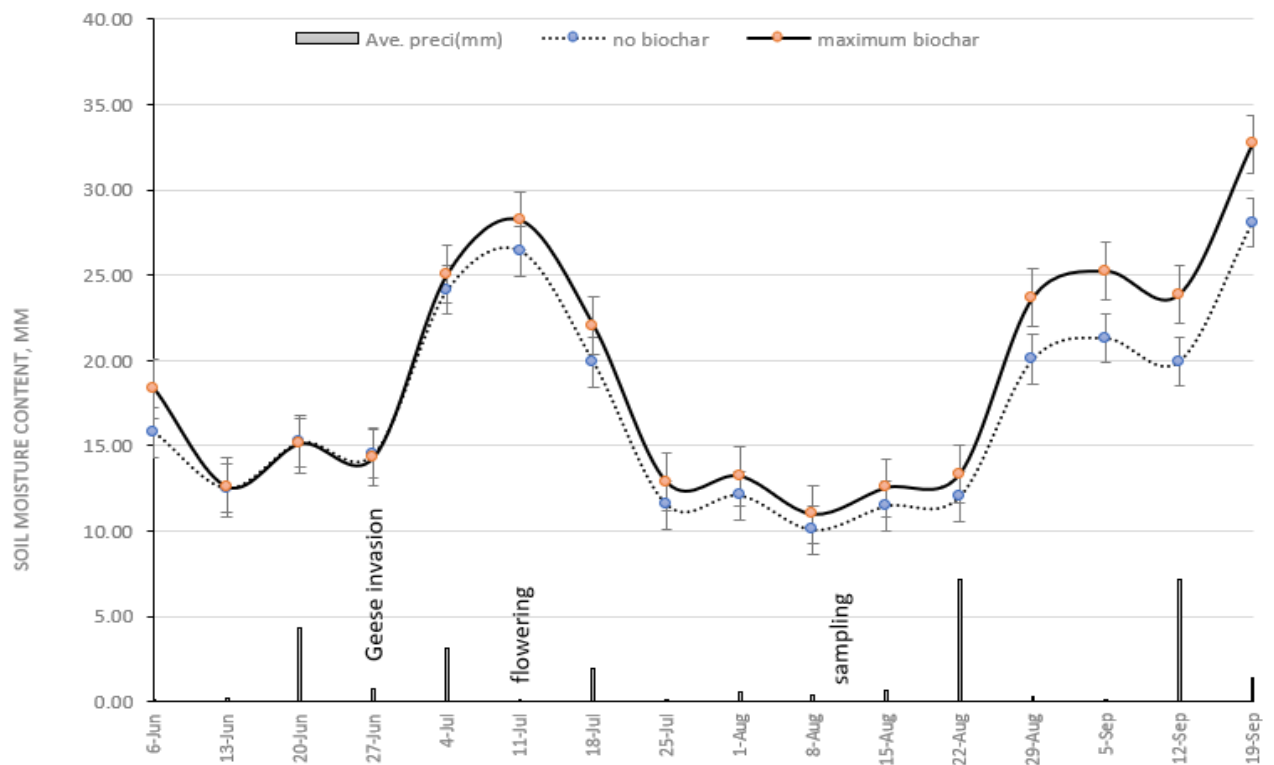
### 4.3 Data Analysis

Statistical analysis of the data from the experiments were conducted with software package SPSS v 25.0 (SPSS Corp., Chicago, USA). A two-way split-plot analysis of variance (ANOVA) was carried on the data by setting the biochar and fertilizer levels and their interactions as fixed parameters. To compare treatment means, the Tukey HSD multiple pairwise test was used with statistical significance,  $p < 0.05$

## 5. RESULTS

### 5.1 Soil moisture content

The addition of biochar was tied to slightly elevated levels of soil moisture at the upper soil layers (0 – 18 cm) (figure 8). This increase was however not significant for any of the weeks measured ( $p > 0.05$ ). A similar result was obtained for the deeper layers of the soil. Post-harvest soil moisture levels were higher in the upper soil layers than the levels measured during the growing season (figure 8). This increase was however not statistically significant. The effect of fertilizer was very significant in half of the weekly measurements. There was no significant interaction between biochar and fertilizer additions.



**Fig. 8** The moisture content of upper soil layer (0 – 18 cm) measured during the season as compared to the mean weekly precipitation during the period. Harvest was conducted week 14.

### 5.2 Soil chemical properties

Neither the soil carbon nor nitrogen content was significantly affected by addition of biochar. Consequentially, the Carbon: nitrogen (CN) ratio was not significantly affected. ( $p > 0.05$ ) (fig. 9). The interaction between fertilizer and biochar did also not produce any significant effects. Similarly, soil pH was not significantly affected by neither incremental addition of biochar nor fertilizer. The interaction of the biochar and fertilizer also did not significantly affect the pH.

Soil electrical conductivity was not affected by incremental addition of biochar. Biochar addition did not significantly affect the levels of most of the soil nutrient elements including boron, Ca, K, P, Mg, Mn, Zn, Cu, etc. (table 4). However, biochar addition was only responsible for marginal increase in soil sulphur (S) content ( $p < 0.1$ ). There were significant effects of fertilizer application on the levels of five elements including Ca, P, Mg, K and S. Biochar – fertilizer interactions were only responsible for significant increase in levels of Ca ( $p = 0.011$ ). A significant interaction was recorded for Ca levels (0.011)

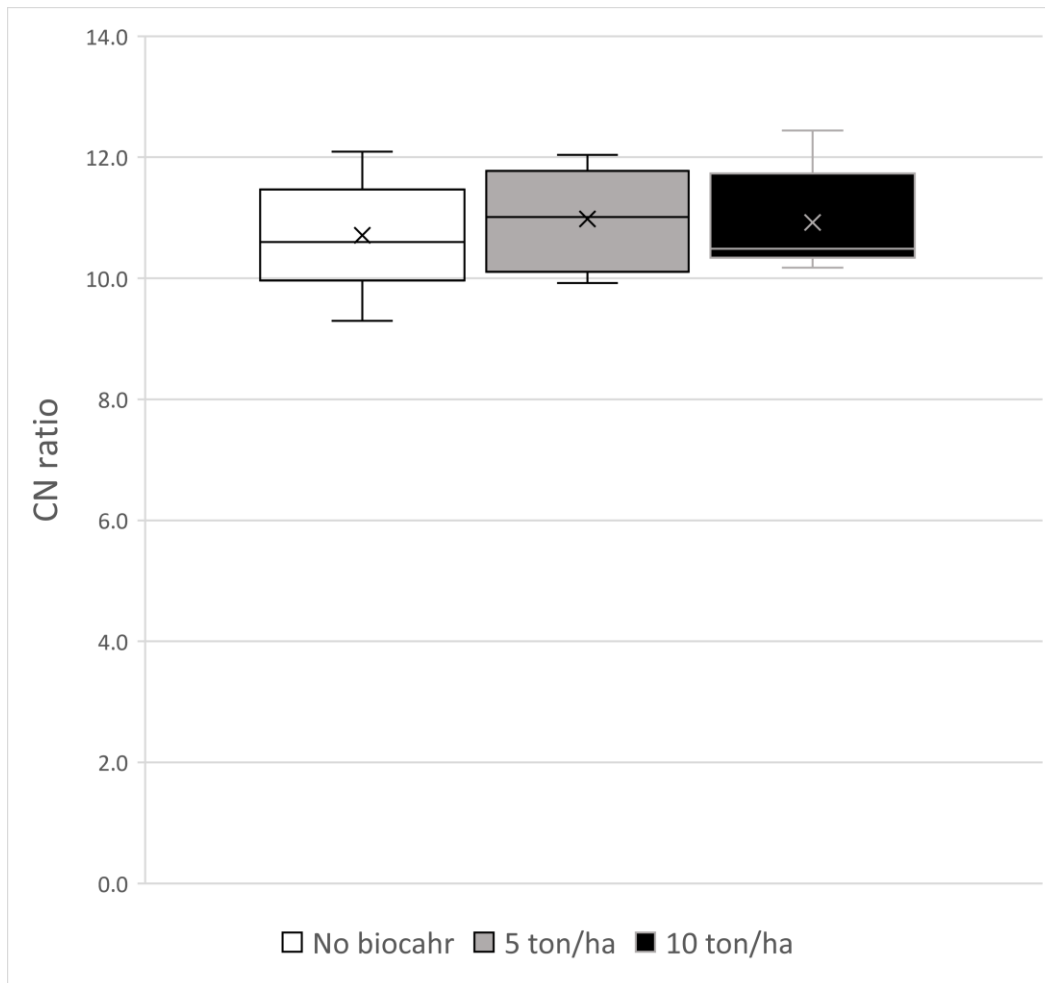


Fig. 9: The main effects of the different biochar application rates on the CN ratio

**Table 4.** The physicochemical parameters of the soil in the various treatments. Data show means of 4 replicates across 3 treatment levels. P-valued that are boldened show indicates statistical significance using Tukeys's HSD test at significance level of  $p < 0.05$ . B0, B5 and B10 represent biochar application rates of 0, 5 and 10 ton/ha respectively. Similarly, F30, F65 and F100 are the rates of application of fertilizer used.

Treatment	El. Con.	pH	Ca	K	P	Mg	S	Cu	Zn	Mn	Na	N	C
B0	1.24a	6.28	1769.17	191.67	13.58	215.83a	17.17	16.42a	4.75	6.08	10.00a	2.69	23.24
B5	1.37b	6.28	1799.17	179.17	14.33	225.83b	21.08	17.58b	5.37	6.77	11.75b	2.61	22.12
B10	1.32ab	6.29	1749.17	194.17	13.57	213.33a	18.92	18.00b	5.67	6.43	10.83b	2.69	22.79
SEM	0.03	0.01	14.53	4.64	0.25	3.82	1.13	0.47	0.27	0.20	0.51	0.03	0.33
F30	1.18a	6.28	1814.17a	170.00a	12.91a	219.17	15.75	17.25	5.01	6.31	10.92	2.77	24.15
F65	1.32b	6.31	1779.17ab	191.67b	13.82ab	218.33	19.58	17.58	5.51	6.49	10.58	2.58	21.80
F100	1.43b	6.25	1724.17a	208.33b	14.75b	217.50	21.83	17.17	5.27	6.48	11.08	2.63	22.20
SEM	0.07	0.02	26.19	11.10	0.53	0.48	1.77	0.13	0.14	0.06	0.15	0.06	0.73
<i>p</i> -values													
BC	0.299	0.824	0.376	0.276	0.206	0.147	0.0830	0.192	0.502	0.419	0.608	0.221	0.364
F	<b>0.0002</b>	0.214	<b>0.019</b>	<b>0.001</b>	<b>0.001</b>	0.7030	<b>0.0003</b>	0.409	0.445	0.812	0.387	0.200	0.072
BC × F	0.3550	0.628	<b>0.011</b>	0.936	0.975	0.8340	0.5270	0.100	0.338	0.374	0.433	0.563	0.767

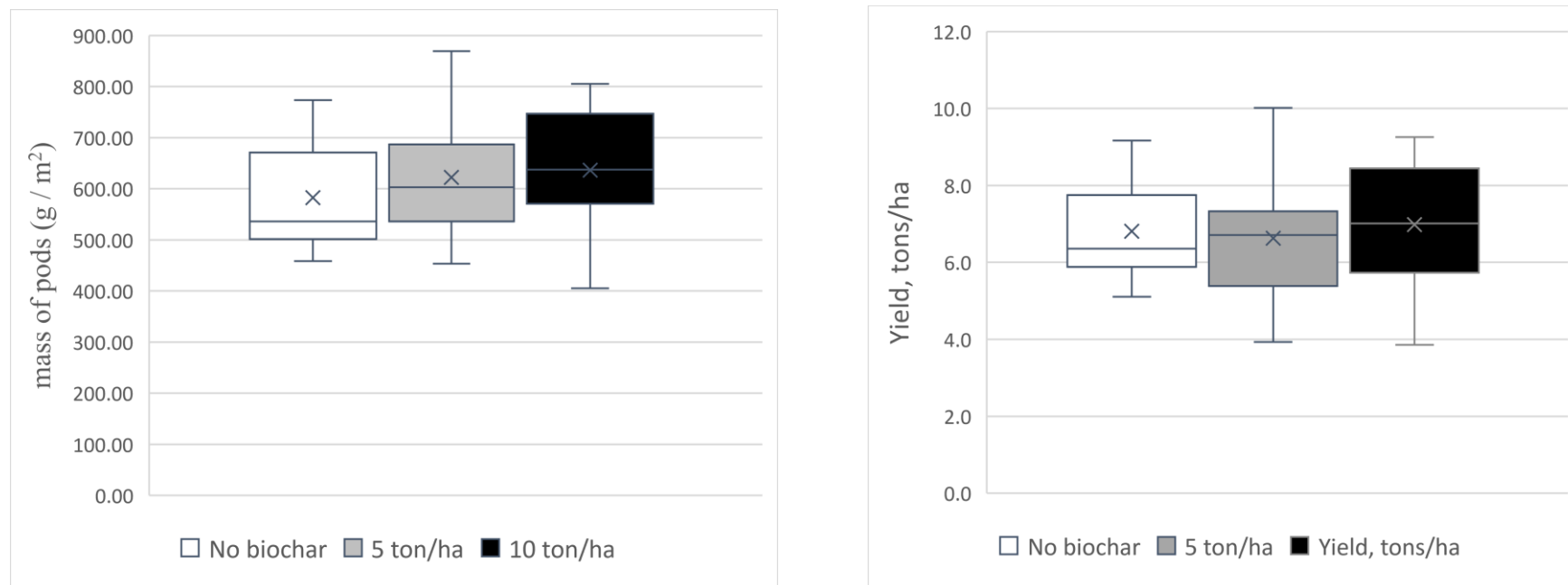
### 5.3 Effects of biochar on yield components

None of the different biochar treatments had any significant effect of any of the measured yield components. For example, the addition of 10 ton / ha biochar was associated with increased mass of pods per square meter (fig. 10). This increase was however not significant (Table 5). The mean mass of pods / m<sup>2</sup> increased significantly (table 5) with increasing rate of biochar application compared to the control treatments. The highest mean mass of pods/m<sup>2</sup> was 869.33 g/m<sup>2</sup> obtained from the **B1** (i.e. 5 ton / ha biochar with least fertilizer level) with the lowest mean mass of pods/m<sup>2</sup> recorded for the **C2** (i.e. highest biochar with medium fertilizer). Similarly, biochar additions did not affect significantly the overall yield (tons / ha) of the peas ( $p > 0.05$ ) (fig 6). The highest yield (ton / ha) was recorded for **B1** (medium biochar and lowest nitrogen level as 10.02 ton / ha compared with 3.86 ton / ha recorded with the **C2** (highest biochar with medium fertilizer) being the lowest yield. The effect of fertilizer on the yield was also insignificant (table 5).

The highest pods / shoot ratio was 9.73 recorded for **C1**(highest biochar with lowest fertilizer level). Conversely, the lowest pod / shoot was 3.56 pods / shoot recorded for **B1**. Addition of fertilizer did not significantly affect the number of pods / shoots for all the different biochar treatments. Other yield components such as above ground biomass, number of seeds per pod, vegetative mass, mass of leaves and stems, etc. were also not significantly affected neither biochar nor fertilizer addition. The interactions between fertilizer and biochar was not responsible for any significant effects on yield components (table 5)

**Table 5.** The yield components of pea in the various treatments. Data show means of 4 replicates across 3 treatment levels. P-valued that are boldened show indicates statistical significance using Tukeys's HSD test at significance level of  $p < 0.05$ . B0, B5 and B10 represent biochar application rates of 0, 5 and 10 ton/ha respectively. Similarly, F30, F65 and F100 are the rates of application of fertilizer used.

BC	Mass of leaves (g/m <sup>2</sup> )	Mass of stems (g/m <sup>2</sup> )	Vegetative mass (g/m <sup>2</sup> )	Above-ground Biomass (tons/ha)	Mass of pods (g/m <sup>2</sup> )	Pods / shoot	Seeds / tiller	Seeds / pod	1000 seed weight (g)	Yield, (tons/ha)	HI
<b>B0</b>	72.64	303.99	376.63	11.67	582.67	5.83	29.10	4.95	235.61	6.81	0.58
<b>B5</b>	79.29	325.01	404.30	11.75	622.22	5.65	26.23	4.63	227.45	6.63	0.56
<b>B10</b>	77.03	341.35	418.38	12.34	636.44	6.07	29.55	4.80	228.16	6.98	0.56
<b>SEM</b>	1.95	10.81	12.26	0.21	16.09	0.12	1.04	0.09	2.61	0.10	0.01
<b>F30</b>	79.18	343.87	423.05	12.79	653.78	5.99	28.62	4.75	236.15	7.35	0.57
<b>F65</b>	71.69	301.05	372.74	11.04	584.00	5.87	27.88	4.69	226.61	6.26	0.56
<b>F100</b>	78.09	325.43	403.52	11.94	603.56	5.69	28.38	4.93	228.45	6.80	0.57
<b>SEM</b>	2.34	12.40	14.64	0.51	20.78	0.09	0.22	0.07	2.92	0.31	0.00
<b>p-values</b>											
<b>BC</b>	0.749	0.690	0.711	0.871	0.739	0.744	0.554	0.259	0.438	0.908	0.173
<b>F</b>	0.323	0.096	0.116	0.089	0.206	0.837	0.956	0.536	0.307	0.134	0.751
<b>BC x F</b>	0.537	0.302	0.344	0.356	0.349	0.793	0.369	0.289	0.201	0.382	0.552



**Fig 10.** The main effects of the different biochar application rates on mean mass of pods (g/m<sup>2</sup>) (left) and on the total yield of peas (tons/ha) (right).

No significant effect was produced by the interaction of biochar and fertilizer application

## 6. DISCUSSION

Several studies have contrasting conclusions about the effects of biochar on soil moisture content. Majority of biochar-soil water studies are based on relatively fresh biochars (Wang et al, 2019). According Mia et al. (2017), biochar physical properties change over time as it interacts with soil factors. This is evidenced by the high specific surface area of freshly produced biochar compared to old biochar (Rajapaksha et al., 2016). The decreased surface area in aged biochars result from the gradual filling of spaces between the biochar particles with soil humus (Martin et al., 2012). Many experiments with soils amended with biochar led to higher increased water retention compared to untreated soils (Wang et. al, 2019; Karhu, Mattila, Bergström, & Regina, 2011; Laird et al., 2010; Piccolo, Pietramellara, & Mbagwu, 1996, Karhu et al. 2011; Jones et al. 2012; Gaskin et al. 2007)

In this experiment, no significant increase in soil moisture content was recorded for the different biochar treatments. The lack of effects on soil moisture is consistent results from other cropping years, although a significant increase in soil moisture was observed in 2011 but not in any other year. Like the results from the first 3 growing seasons on the same field (2010 – 2012), fertilizer had no significant effect on soil moisture levels (Tammeorg et al., 2014a). This lack of effects is probably due to the reduced porosity of the eight-year old biochar. This is supported by Hardie et al. (2014) who recorded no improvement in soil porosity and WHC four years after treating sandy loam with biochar. The 2018 growing season was relatively dry compared to the previous two years (Finnish Meteorological Institute). The warmer drier conditions may also have been partly responsible for the insignificant moisture levels recorded. The rate of application of biochar has been reported to affect its effect on soil moisture (Gaskin et al. 2007, Quilliam et al. 2012). Wang et al. (2019) reports that high application rates ( $\geq 10$ ) of biochar can help enhance water holding capacity coarse soils. Gaskin et al, (2007) reported no significance change in water retention in loamy sand soils when lower rates of biochar ( $< 20$  Mg/ha) were used. This seems to imply that the maximum biochar treatment used in this experiment (10 t DM/ha) was inadequate to cause a significant increase in soil moisture.

The effects of biochar on soil chemical composition depends on the type of biochar used and the nature of soil (Mukherjee, Lal 2013). Biochars insignificant effect on soil chemistry has been reported in many experiments in temperate regions (Jones et al., 2012). In this experiment, addition of biochar did not significantly affect the soil chemical composition after eight years of applications. The lack of significant effects on many soil chemical properties including pH,



electrical conductivity and all other measured soil nutrients except C and K content, is consistent with results from earlier experiments on the same field. Following the one-time addition of the biochar in 2010, there was significant increase in soil C ( $p < 0.001$ ) for the first 3 growing seasons; from 2010 – 2012 and K ( $p < 0.02$ ) in 2010 (Tammeorg et al., 2014a). Aging of biochar may lead to changes in composition of elements (Mia et al, 2017). Some of these changes include the loss of organic carbon and other nutrients to the deeper layers of the soil such that it is beneath reach of most crops (Mia et al, 2017; Major et al. 2010b). Similarly, like the soil moisture content, it is possible that the maximum rate of application used in this experiment (10 ton/ha) was too little to elicit any significant effects. Fertilizer application had significant effects on main nutrients such as P, K, S and Ca, and on the electrical conductivity (Table 4). Other nutrient elements were not affected. The soil types used in our experiment, Luvic Stagnosol, is relatively fertile. Therefore, any fertilizer additions may not necessarily lead to significant increases in nutrient levels. Similarly, biochar effects are more pronounced when applied on relatively nutrient deprived soils. The soil used in this experiment is fertile (containing about 3.5% C) hence making any further additions insignificant.

In this experiment, biochar addition was not responsible for any significant increases in any of the measured yield components. This contrasts to earlier results from the same field with Faba bean. From 2010 – 2011, significant improvements in plant number / m<sup>2</sup> and total seeds / plant. Total vegetative mass was also significantly increased by biochar addition in 2010. Subsequent years saw no significant increases in yield components (Tammeorg et al., 2010). Soil amendment with biochar has been reported to increase yield of crops in many experiments. The effectiveness of biochar to increase yield depends on the type of biochar used and the experimental set up (Lehmann, Joseph 2015). Nevertheless, addition of biochar to soils does not always lead to increased yield or biomass. Lentz and Ippolito (2012) recorded no significant increase in yield of corn despite the addition of 24.4 Mg / ha of hardwood biochar during a two-year period. Similarly, Schnell et al. (2012) found no increase in sorghum yield and biomass after application of 3 Mg / ha of sorghum biochar to an alfisol soil. In another experiment on soil treated with 10 Mg / ha of sugar beet pulp biochar, the development of the sugar beet after germination slowed rapidly and led to a reduced yield relative to the control experiment (Gajić, Koch 2012). Thus, biochar application can both increase or decrease crop yield.

In our experiments, biochar did not significantly affect overall yield of the peas eight years after its application. There was an increased number of reproductive parts (pods) per shoot,

however not significant. This is because peas, like most legumes, exhibit very plastic yield components, where one yield component can be compensated for another (Tayo 1980). Previous studies with biochar have produced mixed results. Some studies resulted in increased grain yield (Solaiman et al. 2010) whereas others even led to decreased yield experiment (Gajić, Koch 2012). In a similar biochar studies with oats, Hamalainen (2018) suggested that when soils with relatively lower C content are treated with biochar, increases in yield are reported. Higher application rates of biochar ( $> 10$  ton/ha) may be needed to significant elicit significant increases in yield. However, reporting the effects of biochar on yield components of pea from our experiment should be done with care due to the relatively dry weather observed during the 2018 growing season. The highest mean monthly precipitation recorded during the growing season was 62.3 mm. This was relatively very low compared to the same period in 2016 and 2017 (143 mm and 86.1 mm respectively). The mean monthly temperatures recorded were each at least 2 degrees warmer than the previous two growing seasons. For example, total grain yield in Finland in 2018 was only 2.7 million tons. This is 20% lower compared to the previous year. Therefore, the relatively warm and drier conditions may have been responsible for the low yields recorded despite the addition of biochar

## **7. CONCLUSION**

Biochar as a soil amendment has enormous potential for the improvement of soil and therefore enhancing of crop yields. There are however many gaps missing in the presently available knowledge on how it affects yield of many crops, especially legumes. A lot of the previous studies with biochar have been done with cereals and usually on nutrient deficient soils. Biochar studies on relatively fertile soils and with legumes are lacking. It is therefore recommended that more research be carried out on the various fertilizer-biochar combinations needed to achieve optimum increases in yield of legumes. This study provided information on the possible long-term effects of biochar on yield on soil properties and on the yield components in peas. Even though not many significant results were obtained, the study has added to already existing literature that biochar has great potential for use as soil amendment and that more studies are still needed.

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